Grande Côte Operations

Proposed Groundwater Quality Monitoring Plan – Grande Côte (Appendix 2.7 of Volume 2 of the Definitive Feasibility Study)

June 2010

Umwelt
Environmental Consultants

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Prepared by

Umwelt (Australia) Pty Limited

on behalf of

Grande Côte Operations

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TABLE OF CONTENTS

FIGURES

APPENDICES

1.0 Proposed Groundwater Quality Monitoring Plan – Grande Côte

This document outlines the proposed groundwater monitoring plan for the Grande Côte mineral sand mining project, Senegal.

The monitoring plan is designed to consider key risks to groundwater quality over the entire life of the mining project, and to ensure that sign-off can be achieved at project closure. The key objectives of this monitoring plan are to ensure that sufficient:

- Baseline information is available on pre-project groundwater quality to allow seasonal and other 'normal' variations in groundwater quality to be identified.
- Baseline information is available on existing groundwater quality to identify existing areas of poor water quality.
- Information is available from groundwater quality monitoring to identify the impact of existing land uses not associated with the mine.
- Information is available to define groundwater quality closure criteria.
- Information is available to identify when groundwater quality closure criteria have been attained.

Generally, groundwater quality monitoring is designed to be capable of determining a project's impact on groundwater quality. The numbers, locations and depths of the monitoring wells should be such that the system is capable of the prompt detection of any statistically significant differences in indicator parameters (Nielsen 1991).

Prior to undertaking ongoing monitoring, the groundwater quality should be characterised over the complete site (Nielsen 1991). This provides information which can be used to refine the design of future monitoring programs and a baseline against which any future changes may be compared.

The proposed monitoring plan includes baseline monitoring, operational monitoring and post-closure monitoring of groundwater quality in and around the Grande Côte project area.

The Grande Côte Operations mining permit covers about 445.7 km^2. The current mine plan indicates that the first six years will cover about 1461 hectares and the subsequent years approximately 826 hectares (Earth Systems 2010). The Mineral Separation Plant and Power Station are located within a separate 354.5 hectare site.

2.0 Principles of Groundwater Monitoring Design

Groundwater quality monitoring provides information that can be used to:

a) define baseline groundwater conditions against which future impacts of mining on groundwater can be compared;

b) reduce and effectively limit any risks to the environment from the Grande Côte project;

c) allow appropriate, focused remediation to take place; and

d) manage Grande Côte Operations compliance with water quality standards (discussed further in **Section 2.1**.

Groundwater is used extensively in the Grande Côte area, where it emerges as surface seeps in niayes and is obtained from shallow wells, bores and seepage trenches. There is no flowing surface water in the Grande Côte project area. Groundwater is used for crop irrigation, for household consumption and for stock water (Earth Systems 2010).

Groundwater use in the project area is concentrated around settlements and in agricultural areas. These typically occur where the groundwater body is close to the surface and high levels of organic material are found, which together allow agriculture to proceed. These areas are mostly situated in the niayes, but they also are found in depressions around isolated settlements in the dunes themselves.

Earth Systems (2010) noted that approximately 609 water sources are situated in the dredge path and a further 283 water sources may be temporarily affected at the margins of the dredge path.

Groundwater monitoring should therefore focus on those areas where existing use of the groundwater body intersects with the proposed dredge path.

2.1 Groundwater Quality Management Options & Risk Reduction

Management of groundwater quality at Grande Côte may be undertaken using several options. The choice of management options to be used should be made in the context of the risks associated with each management option.

2.1.1 Elements

The elements of the Grande Côte area exposed to risk from poor groundwater quality include:

- residents, who rely on groundwater for drinking water, washing water, stock water and irrigation water;
- local ecosystems, which use groundwater soaks to survive; and
- GCO, which must define closure criteria with respect to water quality in consultation with the Senegal government to hand over the project site on completion of mining and rehabilitation.

2.1.2 Hazards

Existing hazards affecting groundwater quality that currently (ie, pre-GCO) exist in the Grande Côte project area include hazards originating from existing land uses such as agriculture and human waste disposal and natural processes which cause acidic pH groundwater to develop (see **Section 5.4.2.5** of ESMMP).

Future potential hazards to groundwater quality from the Grande Côte project will be mitigated to prevent adverse effects. The potential hazards to groundwater quality include both physical pollutants and consequential chemical reactions as a result of the mining.

The potential pollutants include:

- discharge to groundwater of hydrocarbons;
- discharge to groundwater of any fertilisers used, whether organic or inorganic;
- discharge to groundwater of contaminants from the proposed landfill;
- discharge to groundwater of contaminants from the proposed sewage treatment facility; and
- discharge to groundwater of any pesticides used.

The potential consequential chemical hazards may include:

- potential generation of acid sulphate conditions by oxidation of framboidal sulphides and/or organic materials; and
- potential concentration of elements in acidic groundwater that are potentially harmful to people, animals or plants.

Although potential hazards to groundwater quality are identified here, the mitigation measures proposed in **Section 2.1.5** are expected to reduce the risk associated with these hazards to acceptable levels.

The potential for acid sulphate generation requires further testwork beyond that undertaken to date. Additional testing will be carried out to understand whether significant or relevant levels of acid sulphate could possibly be generated by the mine operation (Earth Systems, October 2009).

The further testing (based on work to date) is likely to indicate that the potential for acid sulphate generation is relatively small. However, a low level of ongoing groundwater quality monitoring program will be conducted in case of unanticipated acid sulphate generating regions in the project area.

2.1.3 Hazard Ranking

The feasible scenarios for groundwater quality hazards potentially caused by existing land use impacts on groundwater, by natural changes such as declining water tables or by the Grande Côte project or are listed below. The likelihood of these scenarios occurring is also indicated:

1. death of residents, potentially caused by elevated levels of contaminants such as arsenic in the drinking water supply; [**extremely unlikely**]

2. illness of residents, potentially caused by elevated levels of contaminants in the drinking water supply; [**extremely unlikely**]

3. death of stock, potentially caused by elevated levels of contaminants such as arsenic in the stock water supply; [**extremely unlikely**]

4. illness or ill-thrift in stock, potentially caused by elevated levels of contaminants in the stock water supply; [**extremely unlikely**]

5. death of irrigated crops, potentially caused by elevated levels of contaminants in the irrigation water supply; [**extremely unlikely**]

6. death of native vegetation, potentially caused by elevated levels of contaminants in groundwater; [**extremely unlikely**]

7. poor performance of native vegetation, potentially caused by elevated levels of contaminants in groundwater; [**very unlikely**]

8. levels of contaminants in groundwater elevated above national or international standards. [**unlikely**]

Work on groundwater quality undertaken by GCO and Earth Systems to date suggests that there is a very low potential for acid sulphate generation in the project area. If acid groundwater is generated, it has the potential to dissolve, in this context, extremely small quantities of arsenic and other contaminants from the sand. For example, the arsenic concentration at one of the 25 preliminary groundwater quality samples obtained in 2009 already exceeds WHO Drinking Water Quality standards.

2.1.4 Timing and Extent

Some of the potential sources of impacts on groundwater quality will be fixed in space, such as the location of the sewage treatment plant. Others will be potentially moving point sources, such as lubricant stores on the dredge.

Some of the potential groundwater quality hazards, such as from very minor hydrocarbon contamination, only exist when mining activities are taking place. Other hazards may take several years for their greatest impact to become apparent.

In the short term, during mining operation, groundwater will be used from the surficial aquifer (about 90%) and the deep aquifer (about 10%) to maintain the dredge pond at a suitable level. The groundwater management techniques to achieve this and to prevent groundwater flooding surrounding land include two lines of bores along the margins of the dredge path. Pumping of these bores to maintain appropriate water table levels will result in groundwater being retained within the area of the working dredge and the recent tailings. This means that the geographical extent of potential impacts on groundwater quality and levels from dredge operation will be almost entirely restricted to the area between these lines of bores. Modelling indicates that this potential impact will only last for a period of approximately 65 days after the dredge has passed.

Monitoring of groundwater quality around the operating dredge and wet tailings pile will detect rapidly any adverse changes in groundwater quality.

When groundwater levels have been re-established following passage of the dredge, the prevailing groundwater flow directions will be re-established. Since groundwater flows towards the coast in the project area, any potential adverse effects on groundwater quality will potentially only be transmitted a short distance outside the immediate landward side of the mining area.

2.1.5 Management & Remediation

The general approach to be taken towards groundwater quality is to identify suitable monitoring and management techniques during the mining operation to prevent or remediate any issues, if they occur, either before or as they occur.

All of the groundwater quality hazards identified can be remediated and managed. The management and remediation techniques used in other settings include:

- avoiding the discharge of contaminants;
- moving people and groundwater uses away from contaminated areas if they occur; and
- active remediation of groundwater quality.

Grande Côte operations will be avoiding the discharge of contaminants and actively remediating groundwater quality, should it be necessary. Since no people will be living in the path of the dredge and the landscape will be restored following passage of the dredge, it is not expected that any movement of people will be required, in the unlikely event that un-detected groundwater contamination occurred.

2.2 General Approach to Assessing Impacts

A common approach to assessing impacts on groundwater quality is Before-After-Control-Impact (BACI) monitoring. In this approach, the stages refer to:

- Before – The time before any project-related impacts take place.
- After – The time after which any project-related impacts might take place.
- Control – Those areas presumed to be unaffected by the project.
- Impact – Those areas potentially affected by the project.

The groundwater quality monitoring plan should be designed to detect potential impacts from the project before they exceed acceptable levels. This provides greatest protection to the company by minimising risk and takes into account that it is often easier and cheaper to remediate adverse impacts at an early stage.

2.3 'Before' – Existing Land Uses and Groundwater Quality

The acceptability of groundwater quality depends, in part, on what the groundwater will be used for. Within the dunes, groundwater is used mainly for irrigation, stock watering and domestic purposes. At the eastern margin of the dunes, in the niayes, groundwater is used primarily for irrigation and some stock watering.

Impacts on groundwater quality already occur from existing landuses and need to be quantified, before project operations have commenced. The current impacts on groundwater quality include impacts from existing agricultural activities and impacts from existing settlements.

Existing impacts on groundwater quality will continue into the future. The impacts on groundwater quality caused by the Grande Côte project need to be separated from natural variation and from existing impacts on groundwater quality, so that it is clear which changes in groundwater quality are caused by the Grande Côte project.

Existing impacts on groundwater quality and their likely future trends include:

- Generally declining water table and land-use intensification are likely to lead to reductions in available groundwater and possibly to poorer quality groundwater in the long term.
- The intensity of agricultural use of the niayes and in the intra-dune depressions is likely to increase in the future as local populations continue to increase, adding further contaminants to groundwater through increased use of pesticides and fertilisers. Existing tree plantations are likely to have a detrimental effect on groundwater quality as they use more groundwater. This may also concentrate groundwater contaminants.
- The existing trend of declining local water tables suggests that any 'natural' acid generation from oxidation of sulphides that may currently be taking place is likely to increase in volume in the future as more sulphides and organic material are exposed to the air as the water table declines further.

However, groundwater quality may be abnormally 'good' immediately prior to the dredge arriving, in part because the mine may actually improve groundwater quality during its operation. For example:

- Excluding livestock and market gardening from the dredge path immediately prior to the arrival of the dredge is likely to improve groundwater quality.
- Make-up water from the deep groundwater bore is likely to be of higher quality than existing shallow groundwater and its addition to the dredge pond may improve local surface aquifer groundwater quality.
- Increased rates of recharge during the wet season as a result of increased rainfall may improve water quality.

Sampling groundwater quality 'Before' project operation commences will allow the underlying baseline trends in groundwater quality to be established.

2.4 'After' – Future Land Use and Active/Passive Remediation

In many cases, where groundwater has been adversely affected by mineral sand mining, it has 'self-healed' over a period of time. However, hydrogeological conditions in these areas may differ considerably from Grande Côte.

'Self-healing' is particularly observed with acid generation from sulphides, which will be ameliorated over time as the acid generation potential is depleted by ongoing chemical reactions. The process of amelioration may take 5 years or more, depending on local conditions.

If post-mining groundwater quality is adverse, it may be actively remediated by measures such as lime dressing. Alternatively, it may be passively remediated by leaving the site to 'self-heal'.

Active remediation improves groundwater quality more quickly and allows prior land use activities relying on groundwater, such as domestic uses and agriculture, to recommence more rapidly.

By contrast, passive groundwater quality remediation may restrict other land uses, such as agriculture or settlements on the mined dunes, for a period of time.

'After' monitoring will allow the effectiveness of remediation approaches to be assessed during the post-dredging period and following eventual project closure.

2.5 'Control' Areas

The monitoring of groundwater quality should include some areas that are unaffected by the project activities. These areas will act as 'controls' for comparison with the changes that may be observed in areas affected by project activities.

These control areas might include baseline monitoring at points in the groundwater body that are upgradient from project activities, together with baseline monitoring undertaken prior to the project activities affecting the area.

2.6 'Impacts' Areas

Groundwater quality is potentially affected by impacts from project activities in close proximity to the source of the impact. Groundwater flows slowly through most rock types, including sand. At Grande Côte, the groundwater gradient and hydraulic conductivity suggest a seaward groundwater velocity of about 8.2 metres each year.

In the case of potential point source discharges such as fuel stores or septic systems, groundwater quality monitoring should occur as close as possible to the potential point source.

In the case of potential diffuse non-point sources of contaminants, groundwater quality monitoring should occur throughout the area likely to be affected by the diffuse contaminant. For potential acid sulphate generation, this should be particularly where high organic material concentrations are found in the sand.

2.7 Period of Monitoring

It is important to have baseline information on groundwater quality across a representative section of the project area throughout the project life. This will show the long-term trends in regional groundwater quality and enable conditions immediately prior to the dredge arriving to be put in the context of the long-term trends.

However, it is costly to undertake long periods of intensive groundwater quality monitoring across such a large site. Strategies to reduce the cost of groundwater quality monitoring include:

- Measuring groundwater quality at a large number of sites only occasionally and using more frequent observations at a limited number of sampling sites to understand general changes across the project area.

- Measuring less frequently a limited suite of groundwater quality parameters such as pH and electrical conductivity that can indicate a general decline in groundwater quality, instead of measuring a comprehensive suite of parameters each time.

- Accepting that impacts may occur and committing to remediating to an agreed standard.

To understand how changes observed at a small number of monitoring sites may indicate what is occurring across the wider project area, it is important initially to monitor sufficient sites to understand what variability exists, then to reduce the monitoring intensity later.

The timing and locations of suggested monitoring sites are outlined in **Figure 2**. The following timing of monitoring packages is proposed:

1) Initially up to 90 sites will be monitored twice in one year, prior to the commencement of dredging, using existing groundwater monitoring sites, where possible. The existing sites may also include bores established for pumping along the margins of the dredge path.

2) In the second year, a reduced set of 30 monitoring sites will be sampled every three months, for a year.

3) In the third and subsequent years, this reduced set of 30 monitoring sites will be sampled every six months.

4) A group of monitoring sites around the operating dredge will be sampled from the collection of up to 90 sites outlined in 1). These sites will move with the dredge, to monitor impacts potentially caused by the dredge, for 12 months before and 12 months after the dredge moves through a particular area.

For comparison, there are an estimated 892 water sources in the dredge path or at its margin. As a proportion, the 90 sampling sites are approximately 10% of the total number of water sources.

3.0 Monitoring Parameters

The following parameters are proposed for the monitoring program. The types of contaminants detected by these parameters are indicated in **Table 3.1**. Some parameters may not be required (and can be removed from monitoring parameter suites further on in this document) if the potential contaminant is not used during the operation. For example, if no organophosphate pesticides are used by GCO in revegetating mined areas, organophosphate monitoring would not be required.

Some parameters, such as pH, should only be measured in the field using portable instruments, since the samples will no longer be representative if transported. For other parameters the sample can be stabilised and transported carefully, usually in ice, to a laboratory for testing as soon as possible. For the remaining parameters, longer transport distances are feasible.

Table 3.1 – Suggested parameters for Groundwater Quality Monitoring

Parameter	Indicator For?	Locations for Observation
pH	Suitability of groundwater for domestic & commercial uses; Ability of water to transport potentially harmful chemicals.	All locations
Electrical Conductivity (EC)	Indirect measure of water salinity; One of the most common & convenient methods used to test water. EC changes as the sample is transported, so should be observed in the field and in the lab.	All locations
Faecal coliforms	Contamination of groundwater by human or animal faeces	Near toilet facilities or sewage treatment facilities
Organophosphates	The basis for many herbicides and insecticides. If these chemicals are used during revegetation, potentially may affect groundwater quality.	If herbicides or insecticides used by mine, close to area of use
Potassium	Contamination from fertiliser use	If fertilisers used by mine, in area of use
Nitrates	Contamination from fertiliser use (including animal dung), septic systems, thin soils	If fertilisers used by mine, in area of use
Hydrocarbons	Contamination by fuels and/or lubricants	Where fuels and lubricants are stored or machinery refuelled/lubricated
Iron	Levels of dissolved iron (Fe^{2+}) in groundwater are an indicator for acid sulphate processes occurring	Where potential for acid sulphate generation exists
Sulphate	Inorganic sulphide is not very soluble in natural waters, so sulphate is used as an indicator of the level of sulphide being oxidised	Where potential for acid sulphate generation exists
Arsenic	Levels of dissolved arsenic in groundwater are an indicator for acid sulphate processes occurring, where soluble arsenic is available	Where potential for acid sulphate generation exists and arsenic is available
Chloride	Level of dissolved chloride are an indicator for saline intrusion into the groundwater	Where potential for saline intrusion exists

4.0 Types of Monitoring

Four types of monitoring are proposed for the Grande Côte groundwater body.

1) **Baseline monitoring** is designed to define the pre-project groundwater quality. Later groundwater quality monitoring will be compared with the baseline monitoring to understand how the project and changes to other land-use activities have affected groundwater quality, if at all. In the suggested groundwater monitoring program, an intensive period of baseline monitoring is designated as ‘Snapshot Baseline Monitoring’ and the ongoing period of reduced intensity monitoring is designated as ‘Ongoing Baseline Monitoring’.

2) **Operational Monitoring** is designed to provide early detection of any changes in groundwater quality during the period of mine operational.

3) **Closure monitoring** is designed to provide a snapshot of the groundwater quality at the time the mine closes.

4) **Post-closure monitoring** is designed to provide an ongoing record of groundwater quality when the project has been completed.

The groundwater quality monitoring program is designed to operate in several stages.

4.1 Stage 1 – 'Snapshot' Baseline Monitoring

A snapshot of groundwater quality over the area to be dredged will be obtained for 90 sites on two occasions prior to project commencement. Stage 1 monitoring will show how groundwater quality currently varies across the future dredge path. Water quality parameters that may be affected by project activities will be assessed.

This stage of monitoring provides a complete site characterisation of the conditions immediately prior to project commencement, as a snapshot in time. If future ongoing baseline monitoring (Stage 2) shows that groundwater quality is declining naturally from the snapshot baseline monitoring position, then this trend may be used to argue for a less stringent remediation target for groundwater quality.

4.2 Stage 2 – Ongoing Baseline Monitoring during the Planning Phase

For ongoing baseline monitoring, 30 sites will be chosen from the 90 sites used for Stage 1 monitoring. This sub-set of 30 sites will also be monitored regularly during the project. Stage 2 monitoring will record how regional groundwater quality alters during the project. Water quality parameters that may be affected by project activities will be assessed.

Stage 2 monitoring will be divided into two phases. Phase 1 monitoring will initially sample at a higher frequency than the later Phase 2 monitoring.

During Phase 1 of the Stage 2 monitoring, the 30 sites will be sampled once every three months for one year.

If there is no seasonal variation in groundwater quality during Phase 1, then during Phase 2 the sampling frequency will be once each year.

If there is seasonal variation in groundwater quality in Phase 1, then during Phase 2 the sampling frequency will be once every six months, timed to coincide with the observed periods of variability.

4.3 Stage 3 – Mine Operational Monitoring

During mine operational, the potential effects of operational activities will be monitored. Groundwater monitoring sites will be situated close to the:

- operating dredge;
- mineral separation plant; and
- power generation plant.

When the dredge is operating, the dredge pond will be sampled and additional monitoring sites will be sampled around the dredge 18 months before the dredge arrives. This zone of additional monitoring sites will move with the dredge. This sampling is intended to monitor changes in groundwater quality prior to the dredge's arrival, to provide a localised baseline for potential impacts on groundwater from the dredge. Only water quality parameters that may be affected by project activities will be assessed.

4.4 Stage 4 – Closure and Post-Closure Monitoring

The package of groundwater quality monitoring to be undertaken during mine closure and post mine closure will be identified at a later date.

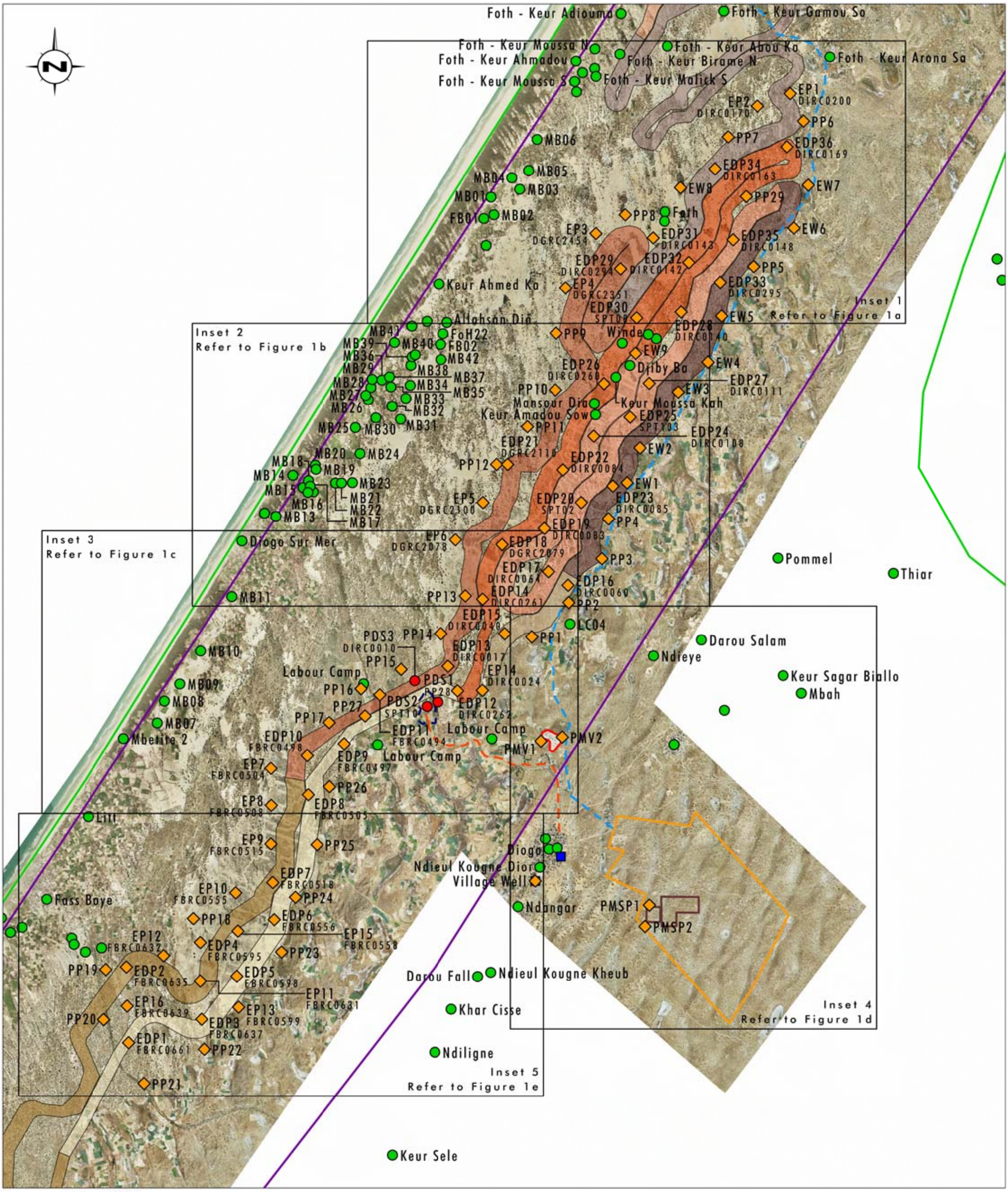
4.5 Groundwater Monitoring Sites

The proposed groundwater monitoring sites are shown in the following figures.

- **Figure 1**, with five insets (**Figures 1a, 1b, 1c, 1d, 1e**), shows the proposed groundwater monitoring points on the Project area.
- **Figure 2** shows the proposed timing of groundwater quality monitoring packages during the project life.
- **Figure 3** shows the proposed sites for ongoing baseline monitoring.
- **Figure 4** shows the proposed groundwater monitoring sites between the Mineral Separation Plan (MSP) and the village of Diogo.

The proposed locations for groundwater monitoring and the parameters to be analysed are summarised in the following tables.

- **Table 9.1** lists proposed existing wells to be sampled.
- **Table 9.2** lists existing piezometers to be sampled.
- **Table 9.3** lists existing dredge path piezometers to be sampled.
- **Table 9.4** lists proposed piezometers to be sampled.
- **Table 9.5** summarises all sampling points to be used for baseline monitoring.
- **Table 10.1** details the groundwater quality parameters to be used for snapshot baseline monitoring.



Source: MDL (2009)
Note: Dredge Path Package as Received from MDL 16/9/09

0 1 2 3km
1:70 000

Legend

Dredge Construction Site	Diogo Mine Constuction Site Road	Dredge Path Package
MSP Site	Baseline Monitoring Site	Year 1 / Year 7
MSP Features	Dredge Contruction Monitoring Site	Year 2 / Year 8
MDL Exploration Camp	Diogo Water Bore	Year 3 / Year 9
Tenement Boundary	Settlement	Year 4 / Year 10
Rural Community Boundary		Year 5
Powerline Along Dredge Path		Year 6

FIGURE 1

Groundwater Sampling/Monitoring Points on Project Site

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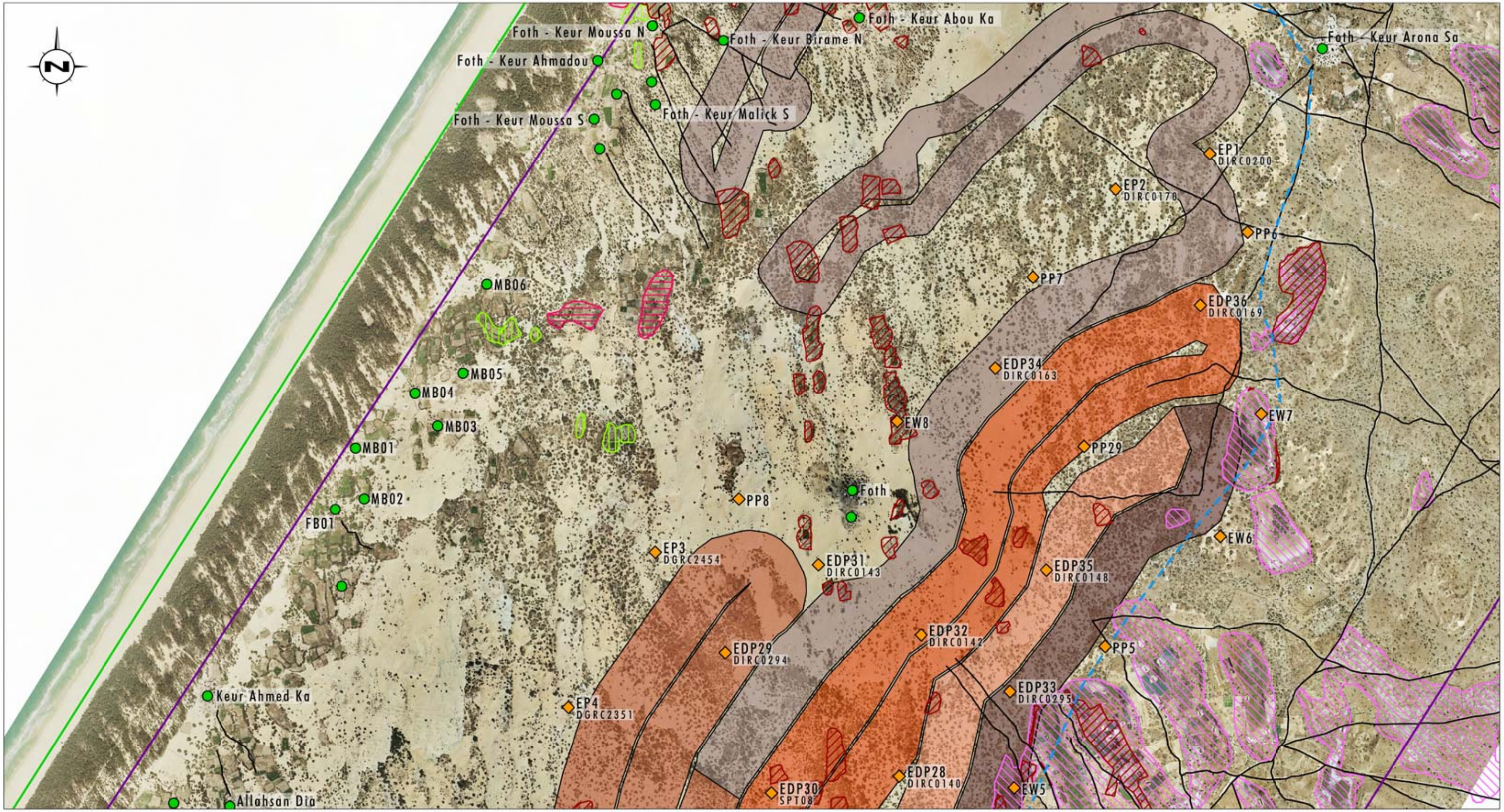

Source: MDL (2009)
Note: Dredge Path Package as Received from MDL 16/9/09

0 0.5 1.0 1.5km
1:25 000

Legend

- Tenement Boundary
- Rural Community Boundary
- Powerline Along Dredge Path
- Road/Track
- Baseline Montoring Site
- Settlement

Dredge Path Package
- Year 2
- Year 3
- Year 4
- Year 7
- Year 8

Land Use
- Garden
- New Garden
- Niayes
- Undefined

FIGURE 1a

Groundwater Sampling/Monitoring Points on Project Site Inset 1

File Name (A4): R11_V1/2261_018.dgn

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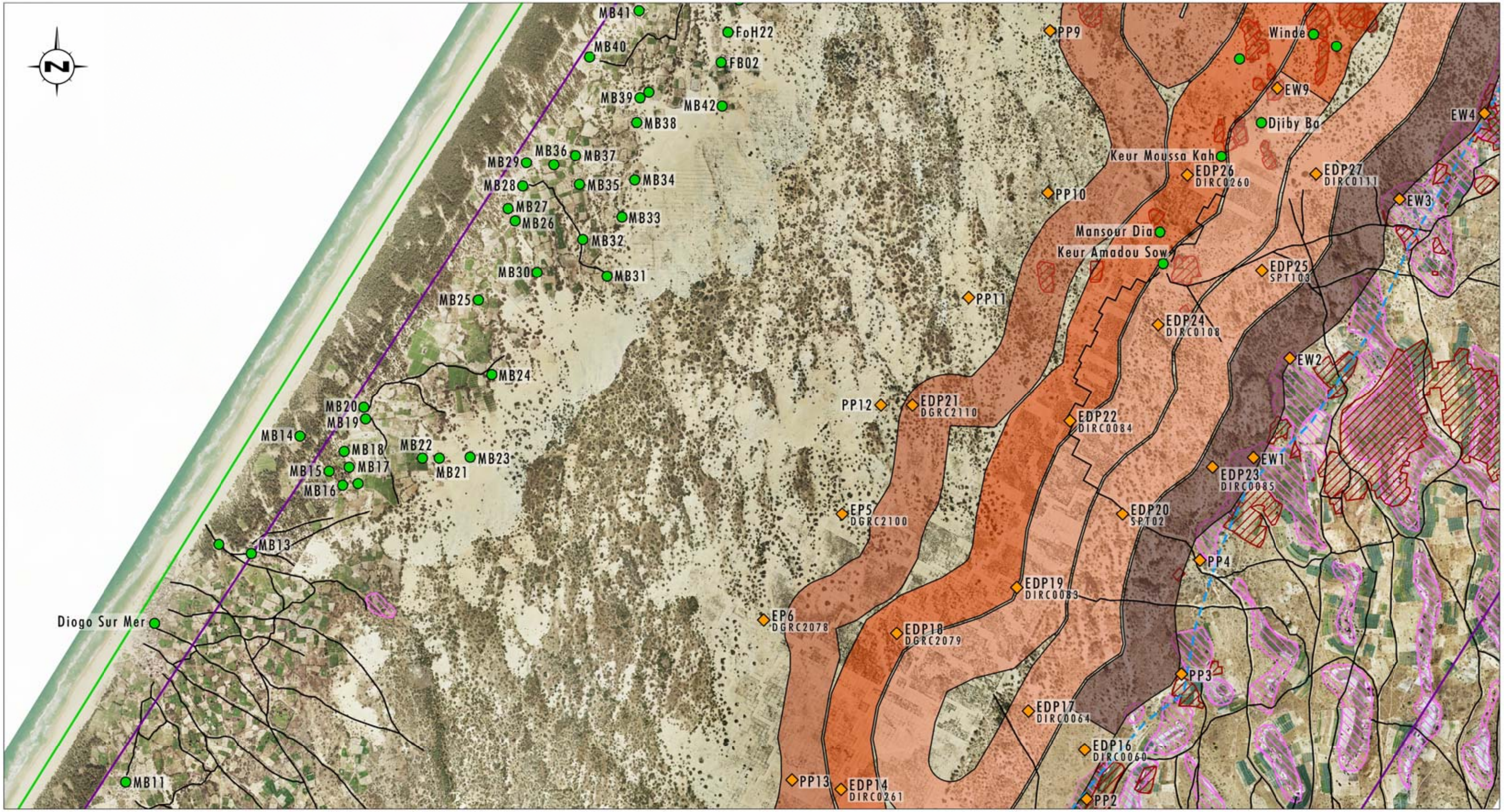

Source: MDL (2009)
Note: Dredge Path Package as Received from MDL 16/9/09

Legend

Tenement Boundary	**Dredge Path Package**	**Land Use**
Rural Community Boundary	Year 1	Garden
Powerline Along Dredge Path	Year 2	Niayes
Road/Track	Year 3	
Baseline Monitoring Site	Year 4	
Settlement	Year 7	

FIGURE 1b

Groundwater Sampling/Monitoring Points on Project Site Inset 2

File Name (A4): R11_V1/2261_017.dgn

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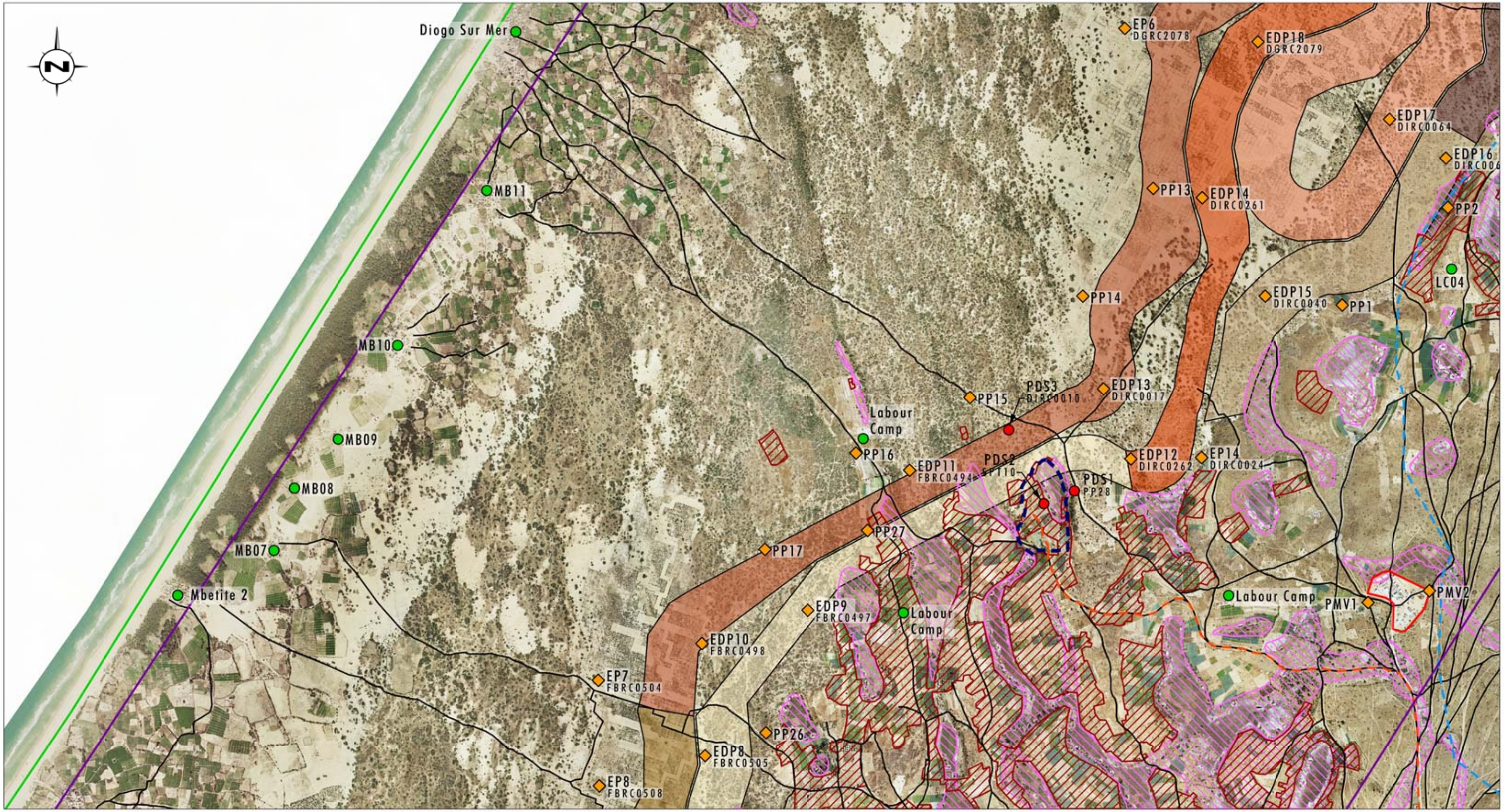


Source: MDL (2009)
Note: Dredge Path Package as Received from MDL 16/9/09

0 0.5 1.0 1.5km
1:25 000

Legend

- Dredge Construction Site
- MDL Exploration Camp
- Tenement Boundary
- Rural Community Boundary
- Powerline Along Dredge Path
- Diogo Mine Constuction Site Road
- Road/Track
- Baseline Monitoring Site
- Dredge Contruction Monitoring Site
- Settlement

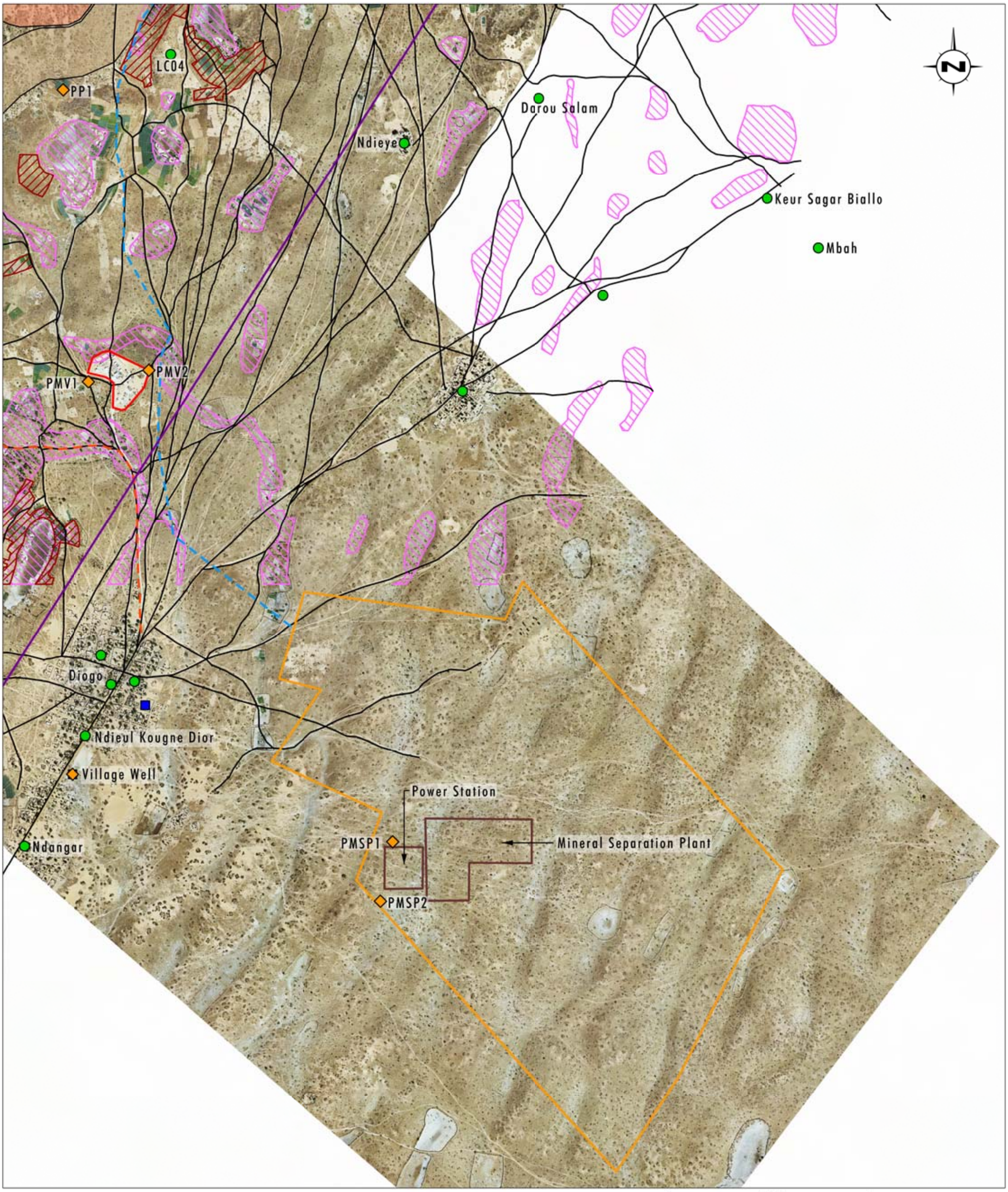
Dredge Path Package
- Year 1
- Year 2
- Year 3
- Year 4
- Year 5
- Year 6
- Year 7

Land Use
- Garden
- Niayes

FIGURE 1c

Groundwater Sampling/Monitoring Points on Project Site Inset 3

File Name (A4): R11_V1/2261_015.dgn



Source: MDL (2009)
Note: Dredge Path Package as Received from MDL 16/9/09

0 0.5 1.0 1.5km
1:25 000

Legend

- MSP Site
- MSP Features
- MDL Exploration Camp
- Tenement Boundary
- Powerline Along Dredge Path
- Diogo Mine Constuction Site Road
- Road/Track
- Baseline Monitoring Site
- Diogo Water Bore
- Settlement

Dredge Path Package
- Year 1
- Year 3

Land Use
- Garden
- Niayes

FIGURE 1d

Groundwater Sampling/Monitoring Points on Project Site Inset 4

File Name (A4): R11_V1/2261_016.dgn

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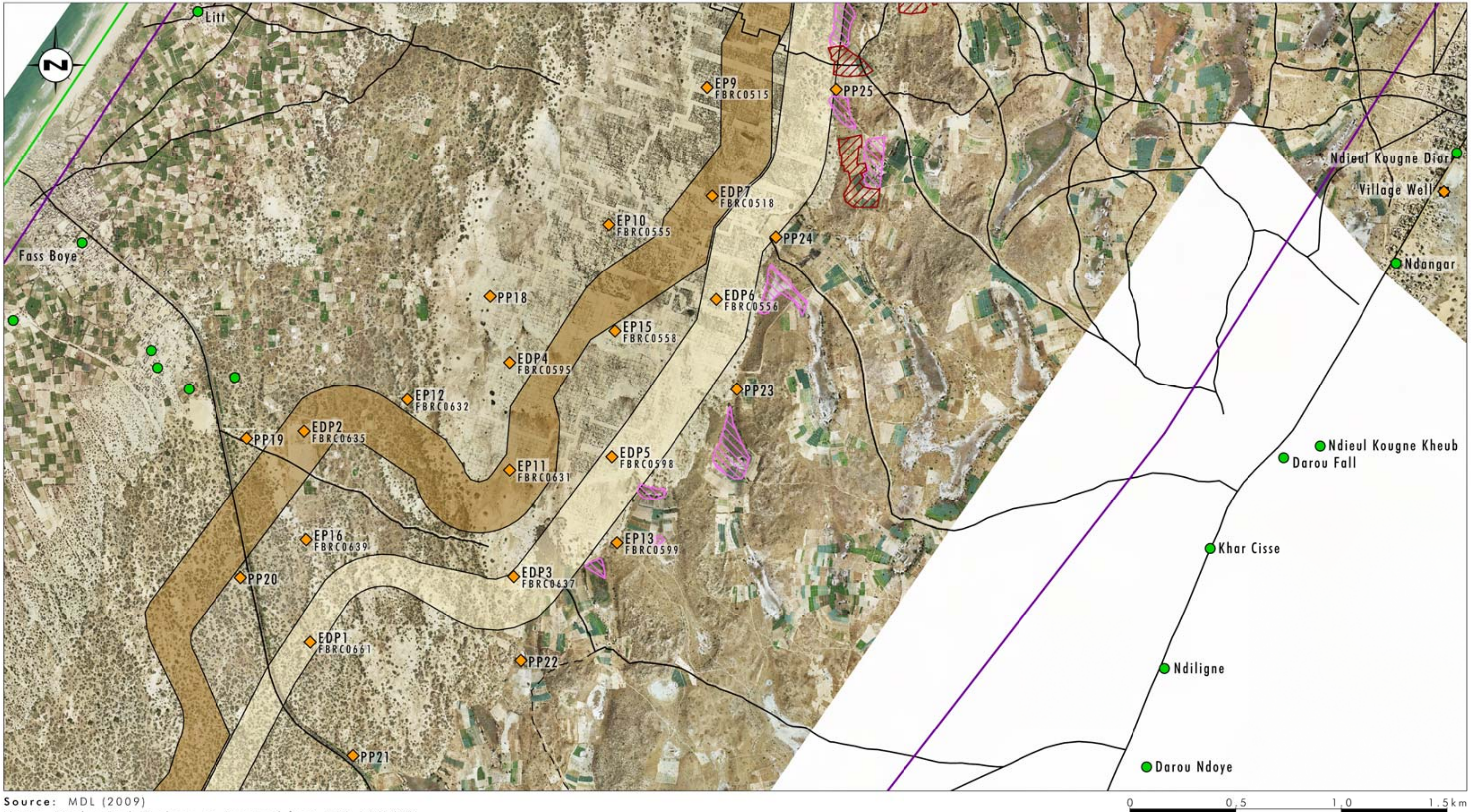


Source: MDL (2009)

Note: Dredge Path Package as Received from MDL 16/9/09

Legend

- Tenement Boundary
- Rural Community Boundary
- Road/Track
- Undefined Road/Track
- Baseline Monitoring Site
- Diogo Water Bore
- Settlement

Dredge Path Package
- Year 5
- Year 6

Land Use
- Garden
- Niayes

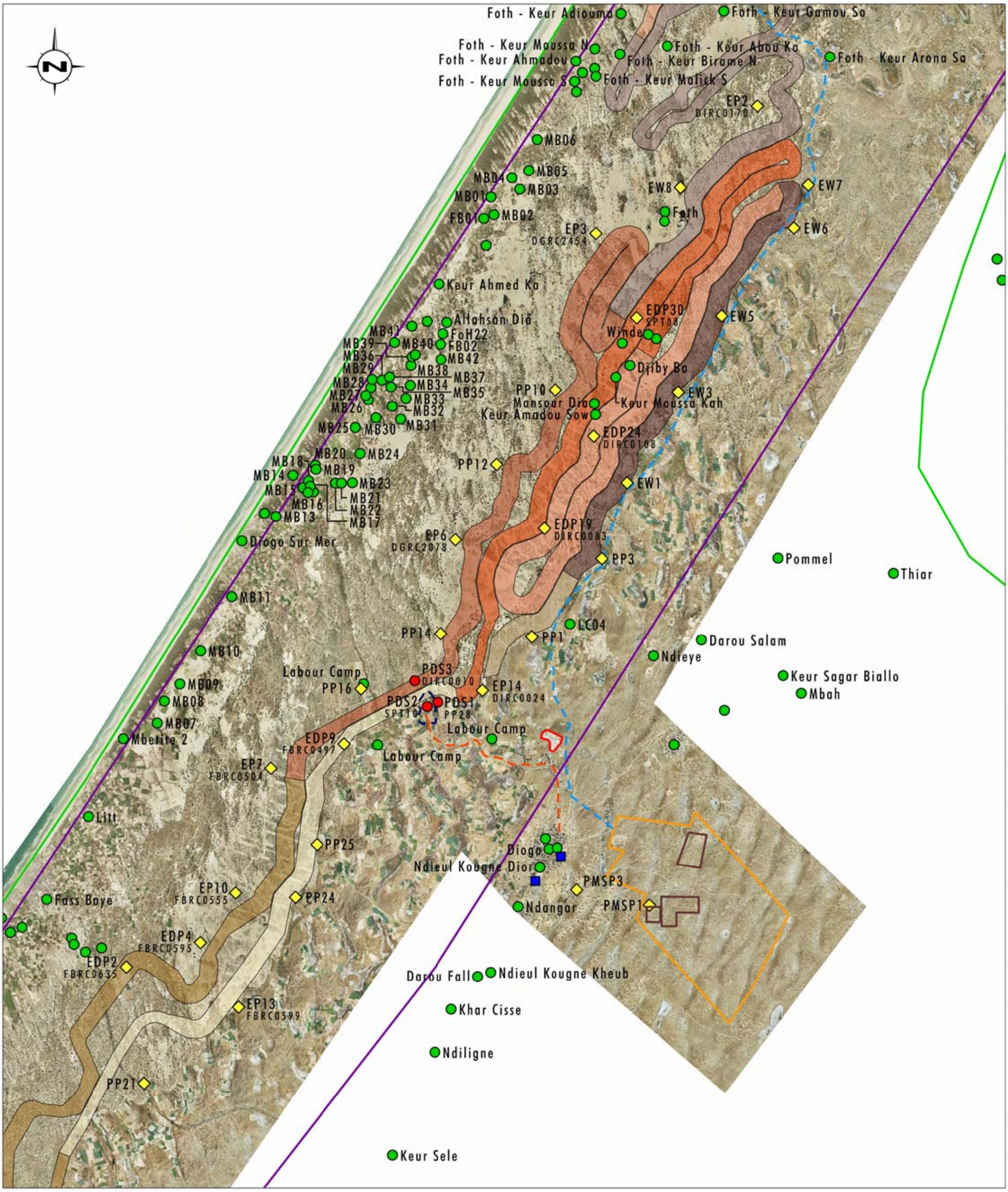
FIGURE 1e

Groundwater Sampling/Monitoring Points on Project Site Inset 5

File Name (A4): R11_V1/2261_014.dgn

FIGURE 2

Timing of Groundwater Quality Monitoring Packages during the Project Life



Source: MDL (2009)
Note: Dredge Path Package as Received from MDL 16/9/09

0 1 2 3km
1:70 000

Legend

- Dredge Construction Site
- MSP Site
- MSP Features
- MDL Exploration Camp
- Tenement Boundary
- Rural Community Boundary
- Powerline Along Dredge Path
- Diogo Mine Constuction Site Road
- Ongoing Baseline Monitoring Site
- Dredge Contruction Monitoring Site
- Diogo Water Bore
- Settlement

Dredge Path Package

- Year 1
- Year 2
- Year 3
- Year 4
- Year 5
- Year 6
- Year 7
- Year 8
- Year 9

FIGURE 3

Sites for Ongoing Baseline Monitoring

File Name (A4): R11_V1/2261_013.dgn

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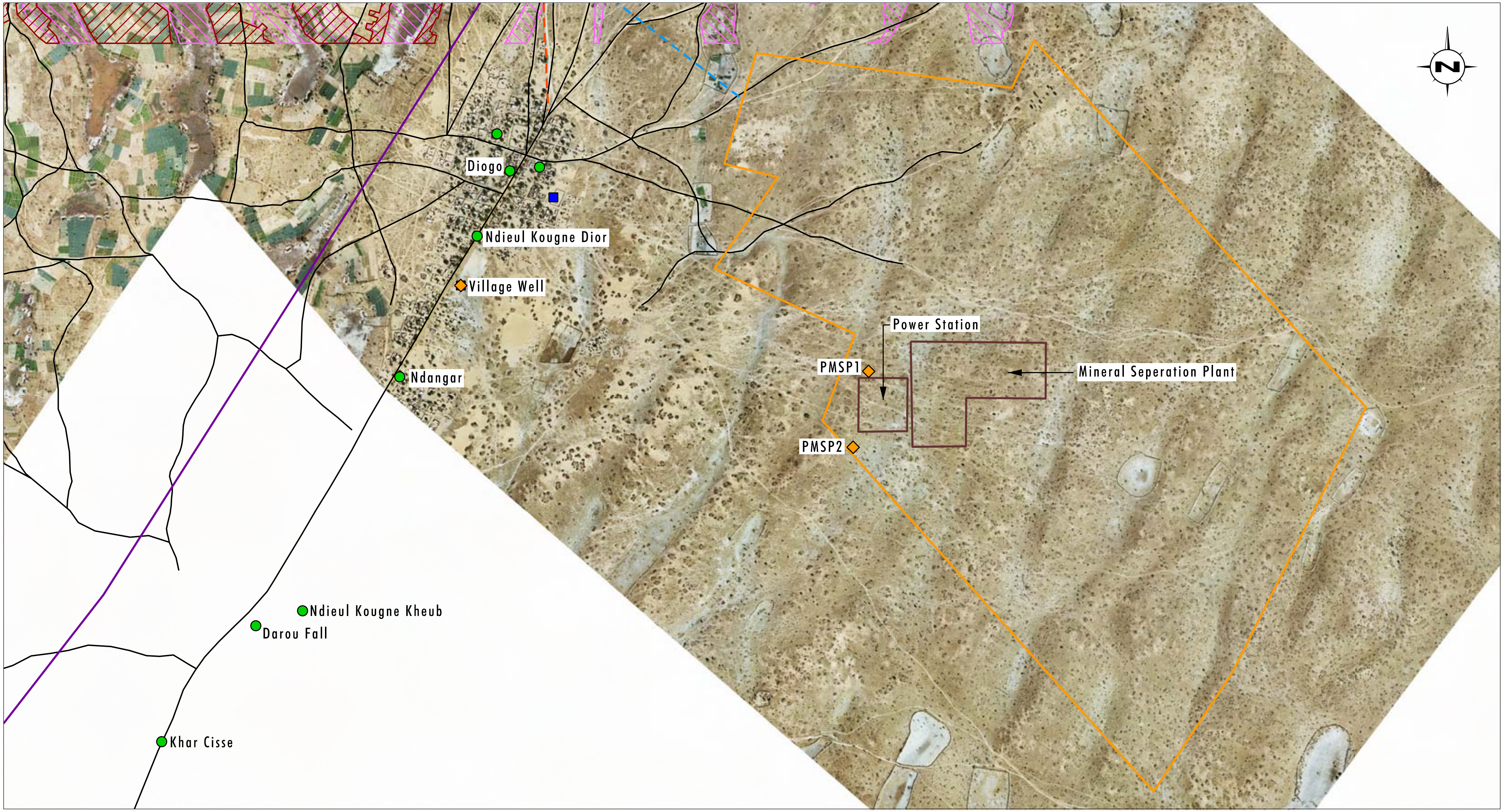

Source: MDL (2009)
Note: Dredge Path Package as Received from MDL 16/9/09

0 0.2 0.5 1.0km
1:20 000

Legend

- MSP Site
- MSP Features
- MDL Exploration Camp
- Tenement Boundary
- Powerline Along Dredge Path
- Diogo Mine Constuction Site Road
- Road/Track
- Baseline Monitoring Site
- Diogo Water Bore
- Settlement

Land Use
- Garden
- Niayes

FIGURE 4

Groundwater Monitoring Sites between the MSP and Diogo Village

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- **Table 10.2** details the groundwater quality parameters to be used for ongoing baseline monitoring.

- **Table 10.3** details the groundwater quality parameters to be monitored on the dredge path.

- **Table 10.4** details the groundwater quality parameters to be monitored at the mineral separation plant and at the power generation plant.

- **Table 10.5** details the groundwater quality parameters to be monitored at the Diogo village water supply point.

Table 11.1 summarises the number of groundwater samples to be monitored during various phases of the project. **Table 12.1** outlines the laboratory location where each of the various water quality parameters may be analysed.

5.0 Potential Sources of Impacts on Groundwater Quality

During the mineral sand mining operation, there are several potential sources for impacts on groundwater quality. These are discussed in **Table 5.1** and include the:

- dredge operation;
- revegetation activities;
- MSP;
- fuel storage areas at the MSP; and
- toilet facilities at the MSP.

Table 5.1 – Potential Sources of Groundwater Contamination

Activity	Potential Contaminants	Potential Impacts	Timing & Location
Dredge operation	Lubricants Fuels Acids from sulphide oxidation or humic decomposition.	Groundwater contaminant levels increase. Groundwater acidification, causing release of further contaminants.	Where dredge operation is taking place during project. Ongoing for up to 6 years.
MSP	Lubricants	Groundwater contaminant levels increase.	During period of operations.
Fuel storage areas, MSP & MC	Fuels Lubricants	Groundwater contaminant levels increase.	During period of operations.

The dredge pond will be higher than the surrounding water table, so no intrusion of saline water from the coast is expected.

The characteristic analyses for contaminants in groundwater and the locations at which they might be monitored are listed in **Table 12.1**.

6.0 Receiving Environment

In the project area, the receiving environment of any potential contamination includes the sand sheet aquifer and the niayes, which are linked to the sand sheet aquifer.

7.0 Existing Groundwater Contamination

Existing groundwater contamination may be caused by existing point source discharges such as pit toilets and animal standing areas. Existing non-point source contamination or nutrient enrichment may be caused by existing fertiliser use.

8.0 Key Elements of the Monitoring Program

The groundwater quality monitoring program will sample in a manner that is adequate to identify:

- natural variations in baseline groundwater quality;
- contamination from specific point sources; and
- contamination from non-point (diffuse) sources.

The sampling needs to be frequent enough to identify natural and mine-induced variations in contamination during the year. The sampling regime also needs to be cost effective and practical.

The groundwater quality parameters chosen for analysis should identify the environmental characteristics of the aquifer and should identify potential impacts on groundwater quality from the mine operation.

9.0 Spatial Distribution of Monitoring Sites

The number of monitoring sites used will increase where features that may be sensitive to groundwater contamination are found (such as water supply points) or where point source discharges may be found (for example around Diogo village).

The piezometric contours in the PSM (2004) report have been used to identify groundwater flow directions from potential contamination sites.

9.1 Mineral Separation Plant, Power Station, Sewage Treatment Plant

East of the village of Diogo, the sampling strategy is designed to monitor any potential contamination from the Power Station, the MSP, and the Sewage Treatment Plant.

Groundwater quality monitoring should occur down-flow from potential sources of point source contamination. At Diogo, this is to the west and north-west of the potential point sources.

Two new monitoring bores are proposed for sites between the Power Station and the villages of Diogo and Ngoye Yawat (**Figure 1d**). These new monitoring bores are named PMSP1 and PMSP2.

Two new monitoring bores are proposed for the site of the proposed sewage treatment plant. The location of these monitoring bores will be determined when the plant location is known. These sites are provisionally named PSTP1 and PSTP2.

It is proposed also to sample the main GCO-provided Diogo Village water supply point.

9.2 Dredge Path

The effects on groundwater quality of mining along the dredge path should be monitored by:

- direct monitoring of the quality of water in the dredge pond, since this is connected to the local groundwater body;
- monitoring groundwater sampled from the existing network of piezometers; and
- installing further sampling points where necessary to provide sufficient points to understand what changes are occurring.

9.2.1 Potential Dredge Path Monitoring Sites

Ninety monitoring sites are proposed around the dredge path at a spacing of approximately 500 to 700 metres. Sixty-one of the 90 monitoring sites exist already. Twenty-nine of the monitoring sites will be new (**Table 9.5**).

The entire collection of monitoring sites should be sampled twice during 'snapshot' baseline monitoring (see **Section 10.1**) during the early period of baseline monitoring.

9.2.2 Fixed Ongoing Baseline Monitoring Sites

A fixed group of 30 of these 90 sites should be sampled for Stage 2 – ongoing baseline monitoring (see **Section 10.2**), both before the start of the project and during the project to understand natural groundwater quality changes on the Project area. Monitoring at these 30 sites should be compared to the original 90 sites. This will show whether the trends observed in the sub-group of 30 can be inferred to apply to the group of 90.

If groundwater quality at sites in the group of 30 show unusual trends, it may be necessary to monitor more sites to obtain sufficient information on the changes observed.

9.2.3 'Moving' Ongoing Baseline Monitoring Sites

During mining an additional group of sites around the operating dredge should be sampled for 18 months around the active dredge to understand in greater detail what groundwater quality variations may exist naturally immediately prior to the dredge arriving.

The sites to be sampled will change as the dredge moves along, but they will be chosen from the larger group of 90 sites sampled for Stage 2 – ongoing baseline monitoring (see **Section 10.2**).

Based on the current mine plan, the dredge will move forward at an average speed of 700 metres per month. At this rate 15 additional monitoring sites will be required in the 'moving' group to monitor for 18 months ahead of the dredge and behind the dredge.

Each month new sites in front of the dredge will be added to the ongoing baseline monitoring package, while sites behind the dredge will be removed from the ongoing baseline monitoring package.

9.2.4 Monitoring Site Locations

Figure 1 and insets shows the location of the 90 proposed baseline monitoring sites in and around the dredge path from which the 30 fixed ongoing baseline monitoring sites and the 15 moving ongoing baseline monitoring sites will be selected.

The proposed monitoring site names indicate whether these sites exist already or may need to be established.

Existing Wells (EW) are mostly wells established for supplying irrigation water. These sites may provide access to the water table for sampling. However, these wells should be inspected before sampling to determine whether water samples can be obtained from the well and to determine the depth of the well.

The Existing Wells to be sampled are outlined in **Table 9.1**.

Table 9.1 – Existing Wells to be Sampled

New Sample Number	Well Number	Easting	Northing
EW1	F023	309297.30	1693693.31
EW2	F003	309466.65	1694152.95
EW3	F064	309974.66	1694888.35
EW4	F114	310366.55	1695285.09
EW5	H122	310545.57	1695894.71
EW6	N027	311498.70	1697055.87
EW7	N031	311687.39	1697621.94
EW8	B025	310003.68	1697588.08
EW9	E051	309408.59	1695401.21

Existing Piezometers (EP) are piezometers outside the proposed dredge path, but close to the proposed dredge path. The Existing Piezometers to be sampled are outlined in **Table 9.2**.

Table 9.2 – Existing Piezometers to be Sampled

New Sample Number	Piezometer Number	Easting	Northing
EP1	DIRC0200	311450.31	1698826.66
EP2	DIRC0170	311014.87	1698662.16
EP3	DGRC2454	308886.06	1696983.30
EP4	DGRC2351	308484.49	1696267.24
EP5	DGRC2100	307395.89	1693432.05
EP6	DGRC2078	307033.02	1692943.40
EP7	FBRC0504	304599.40	1689929.19
EP8	FBRC0508	304604.24	1689440.53
EP9	FBRC0515	304599.40	1688932.51
EP10	FBRC0555	304134.93	1688284.19
EP11	FBRC0631	303665.62	1687123.02
EP12	FBRC0632	303181.81	1687456.86
EP13	FBRC0599	304173.64	1686779.51
EP14	DIRC0024	307388.07	1690958.23
EP15	FBRC0558	304163.96	1687781.02
EP16	FBRC0639	302702.82	1686794.03

Existing Dredge-Path Piezometers (EDP) are piezometers that should be sampled inside the path of the dredge prior to mining. The Existing Dredge Path Piezometers to be sampled are outlined in **Table 9.3**.

Table 9.3 – Existing Dredge Path Piezometers to be Sampled

New Sample Number	Piezometer Number	Easting	Northing
EDP1	FBRC0661	302722.17	1686310.21
EDP2	FBRC0635	302693.14	1687306.87
EDP3	FBRC0637	303684.98	1686619.84
EDP4	FBRC0595	303665.62	1687631.04
EDP5	FBRC0598	304149.45	1687185.92
EDP6	FBRC0556	304642.94	1687931.01
EDP7	FBRC0518	304623.59	1688419.67
EDP8	FBRC0505	305092.90	1689580.83
EDP9	FBRC0497	305567.04	1690253.34
EDP10	FBRC0498	305078.38	1690098.53
EDP11	FBRC0494	306036.74	1690899.79
EDP12	DIRC0262	307060.40	1690952.08
EDP13	DIRC0017	306934.76	1691275.68
EDP14	DIRC0261	307391.05	1692159.61
EDP15	DIRC0040	307681.34	1691704.81
EDP16	DIRC0060	308518.35	1692343.46
EDP17	DIRC0064	308257.09	1692522.47
EDP18	DGRC2079	307647.47	1692880.50
EDP19	DIRC0083	308203.87	1693093.38
EDP20	SPT02	308692.53	1693432.05
EDP21	DGRC2110	307720.05	1693935.22

Table 9.3 – Existing Dredge Path Piezometers to be Sampled (cont)

New Sample Number	Piezometer Number	Easting	Northing
EDP22	DIRC0084	308450.62	1693862.65
EDP23	DIRC0085	309108.61	1693649.77
EDP24	DIRC0108	308857.03	1694307.77
EDP25	SPT03	309336.01	1694559.36
EDP26	DIRC0260	308992.50	1694999.63
EDP27	DIRC0111	309587.60	1695004.47
EDP28	DIRC0140	310013.36	1695947.92
EDP29	DIRC0294	309210.22	1696518.83
EDP30	SPT03	309423.10	1695870.51
EDP31	DIRC0143	309640.82	1696925.25
EDP32	DIRC0142	310114.96	1696601.08
EDP33	EIRC0295	310526.21	1696339.81
EDP34	DIRC0163	310458.48	1697834.82
EDP35	DIRC0148	310695.55	1696901.05
EDP36	DIRC0169	311406.77	1698125.12

Twenty-nine new **Proposed Piezometer (PP)** sampling locations are identified, with 28 outside the dredge path and one inside the dredge path. These sampling locations provide adequate coverage of the project area. The locations of the Proposed Piezometers are given in **Table 9.4**.

Table 9.4 – Proposed Piezometers to be Sampled

New Sample Number	Inside/Outside Dredge Path	Easting	Northing
PP1	Outside	308038.29	1691663.33
PP2	Outside	308527.54	1692115.29
PP3	Outside	308965.53	1692693.08
PP4	Outside	309050.55	1693219.17
PP5	Outside	310966.49	1696547.86
PP6	Outside	311624.49	1698463.79
PP7	Outside	310632.65	1698255.74
PP8	Outside	309273.12	1697230.04
PP9	Outside	308358.70	1695667.30
PP10	Outside	308349.01	1694917.38
PP11	Outside	307981.32	1694433.56
PP12	Outside	307574.90	1693935.22
PP13	Outside	307163.66	1692203.15
PP14	Outside	306839.50	1691704.81
PP15	Outside	306316.97	1691235.50
PP16	Outside	305789.60	1690979.08
PP17	Outside	305368.68	1690533.97
PP18	Outside	303573.70	1687945.51
PP19	Outside	302422.21	1687273.01
PP20	Outside	302393.17	1685773.16

Table 9.4 – Proposed Piezometers to be Sampled (cont)

New Sample Number	Inside/Outside Dredge Path	Easting	Northing
PP21	Outside	302925.38	1687505.24
PP22	Outside	303718.85	1688922.83
PP23	Outside	304739.71	1690621.05
PP24	Outside	304923.56	1697471.95
PP25	Outside	305209.01	1685773.16
PP26	Outside	305373.52	1687505.24
PP27	Outside	305842.82	1688922.83
PP28	Outside	306800.79	1690621.05
PP29	Inside	310869.73	1697471.95

The sampling points for water quality are summarised in **Table 9.5**.

Table 9.5 – Summary of All Sampling Points for Baseline Monitoring

Sampling Point Type	Inside/Outside Path	No. of Sampling Points
Existing Wells	Outside	9
Existing Piezometers	Outside	16
Existing Dredge Path Piezometers	Inside	36
Proposed Piezometers	Outside	28
Proposed Dredge Piezometers	Inside	1
	TOTAL	90

When the dredge passes through an area, any existing piezometers will be destroyed. The destroyed piezometers should be re-established behind and either side of the area that has already been mined to permit Stage 2 – ongoing baseline monitoring to continue at substantially the same location. In the sub-group of 30 sites to be regularly sampled, four piezometers may need to be re-established following the passage of the dredge.

The dredge pond should also be monitored daily for field pH and field conductivity and weekly for sulphate, to determine whether the exposure of peat material to oxidation is generating acid sulphate.

10.0 Monitoring Packages

Groundwater quality monitoring should take place in monitoring ‘packages’, which will be used at various times during the project. Some monitoring may be required prior to the start of the project, some during the project and some following the closure of the project.

The monitoring ‘packages’ are divided here into four Stages.

1. Stage 1 – ‘snapshot’ baseline monitoring at two points in time;
2. Stage 2 – ongoing baseline monitoring during the planning phase;
3. Stage 3 – Operational Monitoring; and
4. Stage 4 – closure and post-closure monitoring.

Each monitoring package is designed to detect particular sources of contamination that may arise during that period of the project. The data obtained from all monitoring packages also provides baseline information against which ongoing monitoring may be compared.

The expected timing for the implementation of groundwater quality monitoring packages is shown in **Figure 3**.

10.1 Stage 1 – ‘Snapshot’ Baseline Monitoring Package

Stage 1 monitoring – ‘snapshot baseline monitoring’ will provide a comprehensive snapshot of groundwater quality at two points in time over the full suite of 90 baseline sampling locations. Later, Stage 2 – ongoing baseline monitoring (see **Section 10.2**) will sample fewer sites, with 30 sampling locations. However, the Stage 2 – ongoing baseline monitoring will be compared with the snapshot baseline monitoring.

Comparing results from the 90 Stage 1 – snapshot baseline monitoring sites with results from the 30 Stage 2 – ongoing baseline monitoring sites will allow inferences to be drawn from the smaller number of Stage 2 – ongoing baseline monitoring sites about what may be occurring over the Project area. The 30 Stage 2 – ongoing baseline monitoring sites will represent the changes likely to be occurring at all 90 sites covered in the Stage 1 – snapshot baseline monitoring.

The sites sampled for Stage 1 – snapshot baseline monitoring will also be used for Stage 2 – ongoing baseline monitoring and for Stage 3 – Operational Monitoring.

This sampling should take place as soon as accurate, reproducible testing can be undertaken. Accurate, reproducible testing of water samples will require:

- field workers to be trained and available;
- laboratory arrangements to be finalised; and
- chain of custody properly to be established.

10.1.1 Number of Sites

Figure 1 and insets shows the 90 locations in the extent of the known planned dredge path (whether 8 or 10 years in length) that have been selected for Stage 1 - snapshot baseline monitoring. This covers an area approximately 120 km^2 in size; with one site on average every 1.25 km^2. An additional suite of eight sites is recommended for sampling around the dredge construction site and around the mineral separation plant and the power generation plant (see **Section 9.1** and **Section 9.2**), plus sampling from the Diogo Village water supply point. The total of 99 sites (including the Diogo Village water supply point) proposed for Stage 1 – snapshot baseline monitoring is detailed in **Appendix 1**.

For the Stage 1 – snapshot baseline monitoring, a total of 198 samples will be obtained from the 99 sites, on two occasions, one month apart.

10.1.2 Parameters to be Monitored

A comprehensive range of water quality parameters should be measured, including all parameters (**Table 10.1**) that may later be used to understand changes in water quality.

Table 10.1 – Groundwater Quality Parameters for Stage 1 – Snapshot Baseline Monitoring

Monitoring Phase	Parameters	Frequency	Sites
Stage 1 – Snapshot Baseline [Comprehensive suite of parameters]	1. field pH 2. field electrical conductivity 3. lab electrical conductivity 4. faecal coliforms 5. organophosphates 6. nitrates 7. potassium 8. hydrocarbons 9. iron 10. sulphate 11. chloride 12. arsenic	Two samples, one month apart	99 Listed in **Appendix 1** as 'Stage 1 – Snapshot Baseline Monitoring Sites'.

10.2 Stage 2 – Ongoing Baseline Monitoring Package

Stage 2 – ongoing baseline monitoring will provide an ongoing baseline of groundwater quality on the whole of the Project area, with fewer sample sites than the Stage 1 – snapshot baseline monitoring. The Stage 2 – ongoing baseline monitoring will provide a series of groundwater quality observations for the whole of the project life, to record natural variations in groundwater quality due to climate and to land-use activities.

In **Stage 2 – Ongoing Baseline Phase 1 sampling**, the sampling frequency for ongoing baseline monitoring should be at one sample every two months (bi-monthly) in the first year, to provide sufficient information to identify changes due to seasonal weather and land-use activities prior to the dredge beginning operation, such as from fertilisers used during the Japanese revegetation project.

The frequency for **Stage 2 – Ongoing Baseline Phase 2 sampling** should be designed to detect any seasonal variability observed in Stage 2 – Ongoing Baseline Phase 1 sampling. If seasonal changes are observed during Phase 1 sampling, it may be necessary each year to obtain one sample at the end of the wet season and one six months later. If no significant seasonal changes are observed in groundwater quality, the sampling frequency could be lowered to one sample each year.

10.2.1 Parameters to be Monitored

The Stage 1 – snapshot baseline monitoring and Stage 2 – ongoing baseline monitoring may be used as the reference for any changes that take place during mining. Therefore, both Stages of baseline monitoring should include all groundwater quality parameters that may later be used for comparison with baseline (**Table 10.2**). Monitoring for some of these parameters such as organophosphates, hydrocarbons or coliforms may be discontinued if they are not detected.

Table 10.2 – Groundwater Quality Parameters for Ongoing Baseline

Monitoring Phase	Parameters	Frequency	Sites
Stage 2 – Ongoing Baseline [Comprehensive suite of parameters]	1. field pH 2. field electrical conductivity 3. lab electrical conductivity 4. faecal coliforms 5. organophosphates 6. potassium 7. nitrates 8. hydrocarbons 9. iron 10. sulphate 11. chloride 12. arsenic	Bi-Monthly in first year. Annually after the first year if no seasonal variation occurs. (Six monthly if seasonal variation noted; one sample at end of wet season, one sample six months later).	30 Listed in **Appendix 2** as 'Ongoing Baseline Monitoring Sites'.

10.2.2 Number of Sites

Figure 3 and **Appendix 2** show the 30 sites that have been selected for ongoing baseline monitoring around the Project area over the extent of the known planned dredge path (whether 8 or 10 years in length) and at specific project locations. This is equivalent to one site on average every 5 km^2.

10.3 Stage 3 – Operational Monitoring Package

During the operational phase of the project, there may potentially be effects on groundwater quality from sources including the dredge, the mineral separation plant, the power generation plant, worker accommodation and revegetation activities and the provision of deep bore water used for make-up water.

A higher groundwater sampling frequency and greater intensity of sampling may be necessary to detect transient contamination of the groundwater body from these activities. The components of the mining operation which require the greatest frequency of groundwater monitoring are those that cause effects which move through the landscape – the dredging and revegetation.

The sampling strategy for Stage 3 – Operational Monitoring is designed to detect contamination as it occurs. The potential sources of contamination to be tested for include:

- chemical reactions or effects caused by mixing of deep bore water with surficial groundwater;
- acid sulphate generation from peat layers exposed by dredging;
- iron and arsenic mobilised by any acid generated from peat layers exposed by dredging;
- saline intrusion due to lowering groundwater table levels;
- organophosphates, potassium and nitrates discharged from fertiliser used during revegetation;
- faecal coliforms from toilet sites at the mineral processing site and at the power generation plant; and
- hydrocarbon contamination from fuelling sites and fuel storage facilities at the MSP site.

The monitoring should be designed to monitor at specific locations around particular mining activities. These should include the:

- dredge construction site;
- dredge path; and
- power generation plant.

10.3.1 Dredge Path Sub-Package

As the dredge moves through the dunes, groundwater quality monitoring should take place at an increased intensity prior to the dredge arriving and for up to six years after the dredge has passed, if acid sulphate generation is observed. This approach will provide a baseline for the situation immediately prior to the dredge arriving and provide monitoring of the immediate impact of the dredge as it moves on.

The potential contamination effects on groundwater quality associated with the moving dredge include generation of sulphuric acid from potential acid sulphate in the peat disturbed during dredging and from discharge of hydrocarbons from the dredge. If acid sulphate is generated, it could take several months to a few years for it to become apparent. If this occurs, it should be detected by the Stage 2 – ongoing baseline monitoring program. The monitoring parameters suggested are listed in **Table 10.3**.

The monitoring sites to be used prior to the dredge arriving should be existing monitoring sites selected from the suite of 90 monitoring locations used for Stage 1 – snapshot baseline monitoring. These monitoring sites should include at least three in front of the dredge. At the proposed spacing of monitoring sites, this sampling strategy will cover about three months of dredge working.

Monitoring sites should be reinstated after the dredge has passed at the same location as the sites prior to dredging, within one month of the dredge passing. Water samples should also be taken from the dredge pond.

The sampling frequency should be:

- fortnightly during initial dredge operation (first two months);
- monthly when the dredge has operated for an initial period of two months; and
- weekly when areas containing potential acid sulphate generating areas are being worked, as identified from prior investigation or from *in situ* tailings sampling.

Hydrocarbons will be monitored by visually inspecting the hydrocarbon reservoirs on board the dredge to ensure leaks are not occurring.

Table 10.3 – Groundwater Quality Parameters for Dredge Path

Monitoring Phase	Parameters	Frequency	Sites
Stage 3 – Operational – Dredge Path [Limited suite of parameters]	1. field soil and water pH 2. field electrical conductivity 3. lab electrical conductivity 4. chloride 5. iron 6. arsenic	Fortnightly during first 2 months; Monthly following first 2 months of operation; Weekly in PASS areas, (except hydrocarbons).	Moving suite of 5 sites, selected from the list of sites identified in **Appendix 1 -** 'Dredge Path Monitoring Sites'

10.3.2 Mineral Separation Plant/Power Generation Plant Sub-Package

The power generation plant is a fixed component of the project, located near the mineral separation plant site. Potential effects on groundwater quality from the power generation plant and the mineral separation plant site include release of hydrocarbons from lubricants and fuel storage and faecal coliforms from toilet systems.

The two sites to be monitored (see **Table 10.4** and **Figure 1d**) are located between the power generation plant and Diogo and Ngoye Yawat villages in positions where they should detect variations in groundwater quality.

The hydraulic conductivity of the aquifer towards Diogo Village was assessed by AGE (2007) from data in PSM (2006) as approximately 1.8 m/day to 1.9 m/day, although AGE (2007) considers this data to be unreliable. A more recent estimate of hydraulic conductivity for the sand dunes in the area suggests a rate of 14 m/day (PSM 2007).

The hydraulic gradient from the power generation plant/MSP site to the village well is estimated from Drawing 4 in AGE (2007) to be 2.25 metres in 1,400 metres (0.16%).

Using the AGE (2007)/PSM (2006) figure for hydraulic conductivity, the groundwater flow velocity at Diogo Village is estimated to be 1.1 metres each year. Using the more recent PSM (2007) figure for hydraulic conductivity, the groundwater flow velocity is estimated to be 8.2 metres each year.

Groundwater flows north and west from the power generation plant and MSP site. Proposed groundwater monitoring sites PSMP1 and PSMP2 should be situated within 20 metres of potential sources of groundwater contamination at the power generation plant and MSP, such as the fuel storage area.

The monitoring site should be sampled once every year to establish a baseline. If groundwater contaminants are accidentally discharged from the site, they are expected to take around three years to travel 20 metres.

The parameters to be monitored are presented in **Table 10.4**.

Table 10.4 – Groundwater Quality Parameters for MSP/Power Generation Plant

Monitoring Phase	Parameters	Frequency	Sites
Stage 3 – Operational – Power Generation Plant [Limited suite of parameters]	1. field pH 2. field electrical conductivity 3. lab electrical conductivity 4. hydrocarbons 5. faecal coliforms	Annually	2 PSMP1 and PSMP2

10.3.3 Diogo Village Sub-Package

The water supply point at Diogo Village should be monitored during the operational phase of the mine, to provide information on what changes are taking place in the groundwater at the well. Potential effects on groundwater quality at the water supply point include hydrocarbons from lubricants and fuel and faecal coliforms from toilet systems. These effects may not be associated with Grande Côte Project activities.

One sample per month should be assessed for water quality parameters. These parameters are outlined in **Table 10.5**.

Table 10.5 – Groundwater Quality Parameters for Diogo Village Water Supply Point

Monitoring Phase	Parameters	Frequency	Sites
Stage 3 – Operational – Diogo Village [Limited suite of parameters]	1. field pH 2. field electrical conductivity 3. lab electrical conductivity 4. hydrocarbons 5. faecal coliforms	Monthly	1 Water supply point

10.4 Closure and Post-Closure Monitoring Package

The package of groundwater quality monitoring to be undertaken during closure and post-closure should be determined during detailed closure planning and revised in the light of groundwater quality issues experienced during the mine life (if any).

Closure monitoring is likely to involve more comprehensive monitoring of groundwater quality parameters to provide a closure baseline. Post-closure monitoring at six months intervals is planned.

11.0 Summary of Monitoring Program

The timing and location of the groundwater quality monitoring program is outlined here in summary form in **Table 11.1**.

Table 11.1 – Timing and Location of Groundwater Quality Monitoring

Site(s)	**Snapshot Baseline** (comprehensive over Project area)	**Ongoing Baseline** (selected over Project area)	**Operational** (detailed around specific activities)	**Closure & Post-Closure** (details to be decided later)
Dredge path	✓	✓	✓	If required
(no. samples, year 1)	180	180	70	
(no. per year, year 2+)	NA	60-120	60	
MSP/power station, Diogo water supply	✓		✓	If required
(no. samples, year 1)	18	NA	16	
(no. per year, year 2+)	NA	NA	16	
Dredge construction Site (per month)	✓		3	If required

12.0 Analytical Locations

To minimise cost, to maximise accuracy of analyses and to reduce the time required to obtain results from the monitoring program, it is proposed that as much as possible of the water quality monitoring should be performed locally.

The three suggested locations for water quality analyses are:

- in the field, at water monitoring sites;
- at the GCO laboratory at the MSP); or
- at a contracting laboratory.

The water quality monitoring parameters that may be analysed at each location are given below in **Table 12.1**. Some parameters may only be analysed if required.

Note that field samples should be returned to the laboratory as soon as possible and should be stored in appropriately treated bottles at temperatures specified in test protocols.

For tests that can be performed at the MDL laboratory, various testing kits are available from commercial suppliers. All of the following tests are available from Hach using their Pocket Colorimeter II series of instruments, reagent kits or an integrated laboratory instrument such as the DR2800. The instruments are of simple design and the Colorimeters are robust enough for field analysis (if required). They often require no calibration and have step-by-step instructions to complete the tests.

For certain tests such as iron and potassium, the samples will probably require dilution to bring the expected parameter concentration into the range of the instruments being used. This is a standard procedure accommodated by the instrument software.

The costs noted in **Table 12.1** are estimated from information available from equipment and reagent supply agencies. The costs associated with obtaining basic laboratory equipment such as test tubes, beakers and generic reagents such as hydrochloric acid etc. have not been included. A reverse osmosis deionised water system will also be required.

Additional costs may be associated with arsenic determinations, since they may require an additional Pocket Colorimeter to complete.

Table 12.1 – Water Quality Monitoring Parameters and Locations for Analysis

Parameter	**Typical Values at Grande Côte**	**Analysis Location**	**Rationale for Analysis Location**	**Equipment Required**	**Equipment Price**	**Reagent/ Calibration Prices**
Field pH	3.2-6.8	In the field	pH must be measured immediately in field	Field pH meter	**US$447** (sensION1)	US$63 for 3x 500 ml bottles
Field electrical conductivity (µS/cm)	131-1285	In the field	EC alters during transport	Field EC meter	**US$554** (sensION5)	Costs not obtained
Lab electrical conductivity (µS/cm)	NA	MDL laboratory	Provides check on EC alteration by transport	Lab EC meter	**US$554** (sensION5)	Costs not obtained
Nitrate (mg/L)	0.5-135	MDL laboratory	Simple test, unaffected by transport	Chemical test kit machine	**US$3,150** (DR2800)	US$0.60 per test NitraVer 6 Powder Pillow
Sulphate (mg/L)	2.24-213	MDL laboratory	Simple test, unaffected by transport	Chemical test kit machine	Included in DR2800	US$0.43 per test Sulfate Powder Pillows
Potassium (mg/L)	1.75-25	MDL laboratory	Simple test, unaffected by transport	Chemical test kit with machine	Included in DR2800	Costs not available
Iron (total) (mg/L)	3.71-17.6	MDL laboratory	Simple test, unaffected by transport	Chemical test kit machine	Included in DR2800	US$0.29 per test FerroVer Powder Pillows
Arsenic (total) (mg/L)	<0.001-0.004	MDL laboratory	Simple test, unaffected by transport	Chemical test kit	Included in DR2800	Costs not obtained
Atrazine and other organophosphates	NA	MDL laboratory	Simple test, unaffected by transport	Chemical test kit machine	Included in DR2800	Costs not obtained
Hydrocarbons	NA	MDL laboratory	Simple test – presence and raw concentration	Chemical test kit machine	Included in DR2800	Costs not obtained
Faecal coliform count	NA	Contract laboratory	Complex test, unaffected by transport			Costs not available

13.0 Data Management and Reporting

The information collected during the groundwater quality monitoring program should be entered into a spreadsheet or database system. The data will be analysed to monitor for trends in water quality parameters and for variations from baseline levels. Regular reports should be generated and provided to Grande Côte Operations for their assessment.

14.0 References

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APPENDIX 1

Snapshot Baseline Monitoring Sites

Appendix 1 – Snapshot Baseline Monitoring Sites

Piezometer	**Existing Hole**
PP1	
PP2	
PP3	
PP4	
EW1	
EW2	
EW3	
EW4	
EW5	
PP5	
EW6	
EW7	
PP6	
EP1	DIRC0200
EP2	DIRC0170
PP7	
EW8	
PP8	
EP3	DGRC2454
EP4	DGRC2351
PP9	
PP10	
PP11	
PP12	
EP5	DGRC2100
EP6	DGRC2078
PP13	
PP14	
PP15	
PP16	
PP17	
EP7	FBRC0504
EP8	FBRC0508
EP9	FBRC0515
EP10	FBRC0555
PP18	
EP11	FBRC0631
EP12	FBRC0632
PP19	
PP20	
PP21	
PP22	
EP13	FBRC0599

Piezometer	Existing Hole
PP23	
PP24	
PP25	
PP26	
PP27	
PP28	
EP14	DIRC0024
EP15	FBRC0558
EP16	FBRC0639
EDP1	FBRC0661
EDP2	FBRC0635
EDP3	FBRC0637
EDP4	FBRC0595
EDP5	FBRC0598
EDP6	FBRC0556
EDP7	FBRC0518
EDP8	FBRC0505
EDP9	FBRC0497
EDP10	FBRC0498
EDP11	FBRC0494
EDP12	DIRC0262
EDP13	DIRC0017
EDP14	DIRC0261
EDP15	DIRC0040
EDP16	DIRC0060
EDP17	DIRC0064
EDP18	DGRC2079
EDP19	DIRC0083
EDP20	SPT02
EDP21	DGRC2110
EDP22	DIRC0084
EDP23	DIRC0085
EDP24	DIRC0108
EDP25	SPT103
EDP26	DIRC0260
EDP27	DIRC0111
EW9	
EDP28	DIRC0140
EDP29	DIRC0294
EDP30	SPT08
EDP31	DIRC0143
EDP32	DIRC0142
EDP33	DIRC0295
EDP34	DIRC0163
PP29	

Piezometer	Existing Hole
EDP35	DIRC0148
EDP36	DIRC0169
PMSP1	
PMSP2	
PSTP1	
PSTP2	
PMV1	
PMV2	
PMV3	
PMV4	
Village Well	

APPENDIX 2

Ongoing Baseline Monitoring Sites

Appendix 2 – Ongoing Baseline Monitoring Sites

Piezometer	Existing Hole
PP1	
PP3	
EW1	
EW3	
EW5	
EW6	
EW7	
EP2	DIRC0170
EW8	
EP3	DGRC2454
PP10	
PP12	
EP6	DGRC2078
PP14	
PP16	
EP7	FBRC0504
EP10	FBRC0555
PP21	
EP13	FBRC0599
PP24	
PP25	
EP14	DIRC0024
EDP2	FBRC0635
EDP4	FBRC0595
EDP9	FBRC0497
EDP19	DIRC0083
EDP24	DIRC0108
EDP30	SPT08
PMSP1	
PMSP2	

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